The University Of Cincinnati College of Engineering

National Aeronautics and Space Administration

Wideband Reconfigurable Harmonically Tuned GaN SSPA for Cognitive Radios

Seth W. Waldstein
The University of Cincinnati-Main Campus

Miguel A. Barbosa Kortright
University of Puerto Rico, Mayagüez Campus

Rainee N. Simons
NASA Glenn Research Center

Outline

Introduction - Motivation

Benefits & Challenges

Wide-Band Reconfigurable Harmonically Tuned Power Amplifier

- **Inverse Class-F Design**
- **Amplifier Fabrication and Results**
- **Thermal Management**
- **Dual-Band Multi-Network Design**

Power Variability

- **Hybrid Coupler**
- **Balanced Amplifier**

Conclusions and Acknowledgements

Introduction - Motivation

- **Spectrum management issues due to growing user community**
  - **Congestion in the X-Band space-to-ground data links is creating the need for cognitive radio capabilities**

What do we need from transmit power amplifiers in a cognitive communication system?

I. **Re-configurability**
   - **High output power; without sacrificing efficiency**
   - **Operating frequency; without sacrificing efficiency**

II. **Linearity**

Benefits

Decrease in Heat Sink Mass

Higher Efficiency Means

- **Saved DC power**
- **Decreased Heat**
  - **Efficiency is lost primarily through power dissipation within the transistor junction and conductor losses.**
  - **Improved Thermal Reliability**

Potential to Enable Low Cost Cognitive Telemetry:

- **Avoids the need for multiple T_x and R_x modules**

Applications include:

- **NASA Missions**
- **Small Satellites and Spacecraft**
- **Military Unmanned Air Vehicles**
- **Commercial/Amateur Cubesats**

Challenges

Efficiency

- High Efficiency SSPA's require harmonic tuning - such as Class-F and Inverse Class-F designs. Matching circuit is complex and inherently narrow band.

Wideband Devices

- Class-F type wideband harmonic tuning techniques used at lower frequencies are unrealizable at X-band

Power Variability

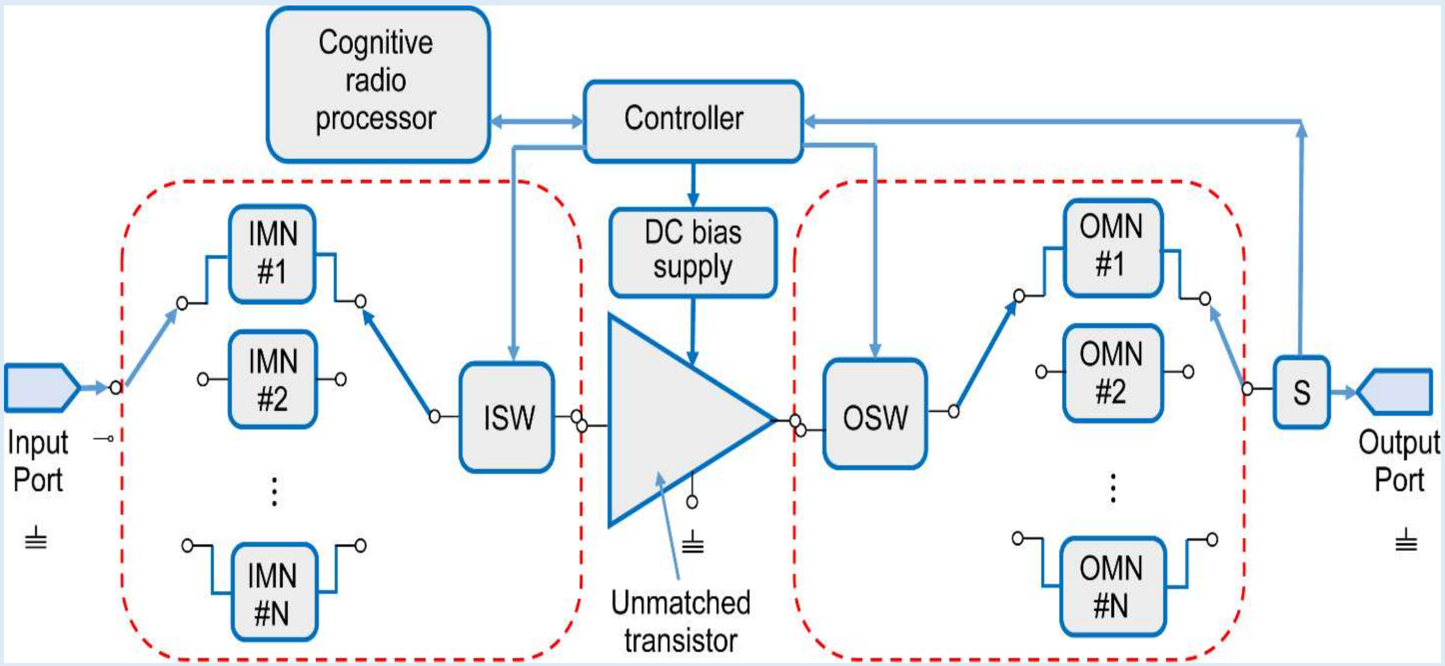
- Amplifiers efficiency drops off when operating below saturation

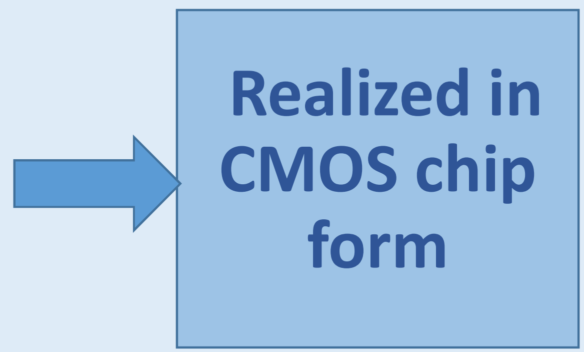
GaN Transistor Frequency Limitation

- Achieving max PAE with Class-F type amplifiers requires F_T > 3rd harmonic
- Current commercially available transistors have an F_T of 18 GHz
- High F_T of GaN HEMTs comes at the expense of feature size and power density

Wide-Band Reconfigurable Harmonically Tuned PA

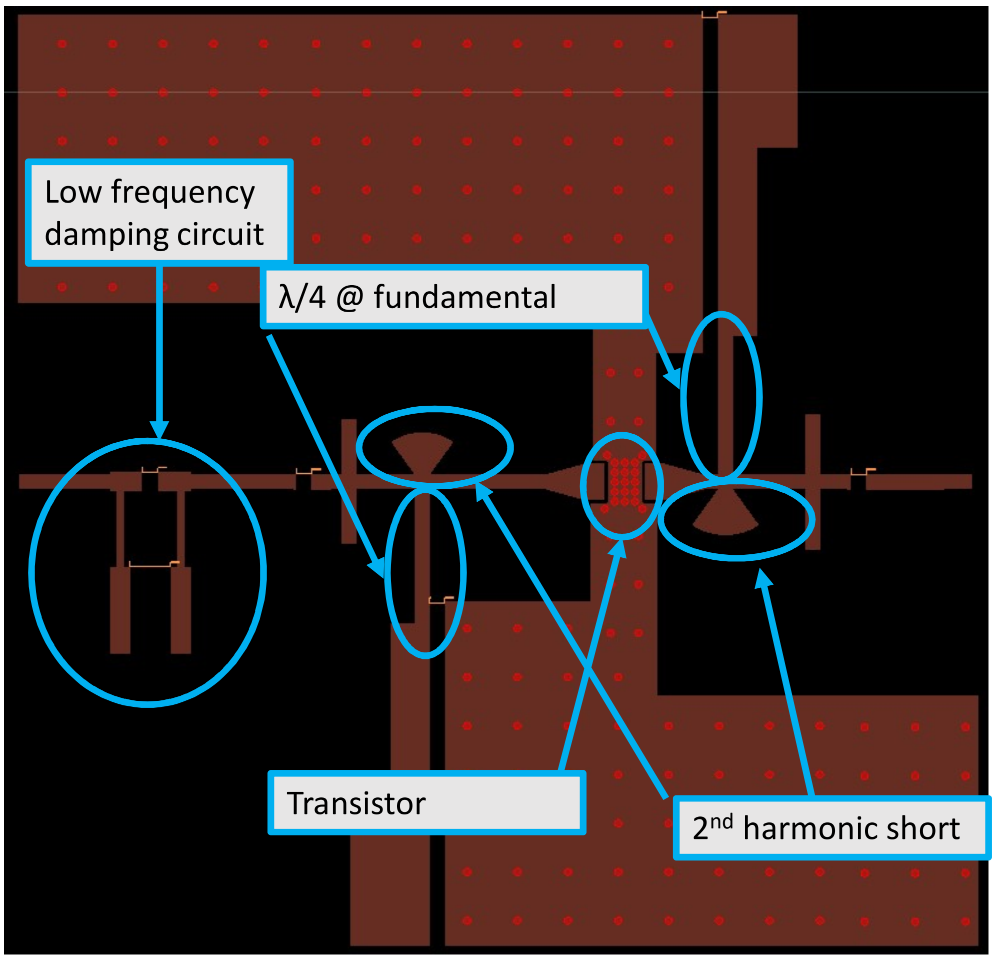
*IMN (Input Matching Network)
*OMN (Output Matching Network)
*ISW (Input Switch)
*OSW (Output Switch)



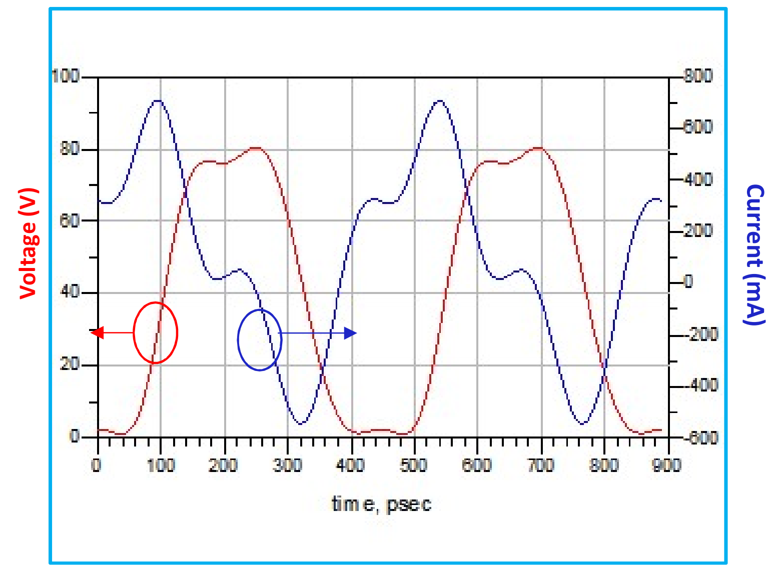


Design to provide wideband high efficiency using multi-network tuning

Inverse Class-F GaN SSPA at X-Band

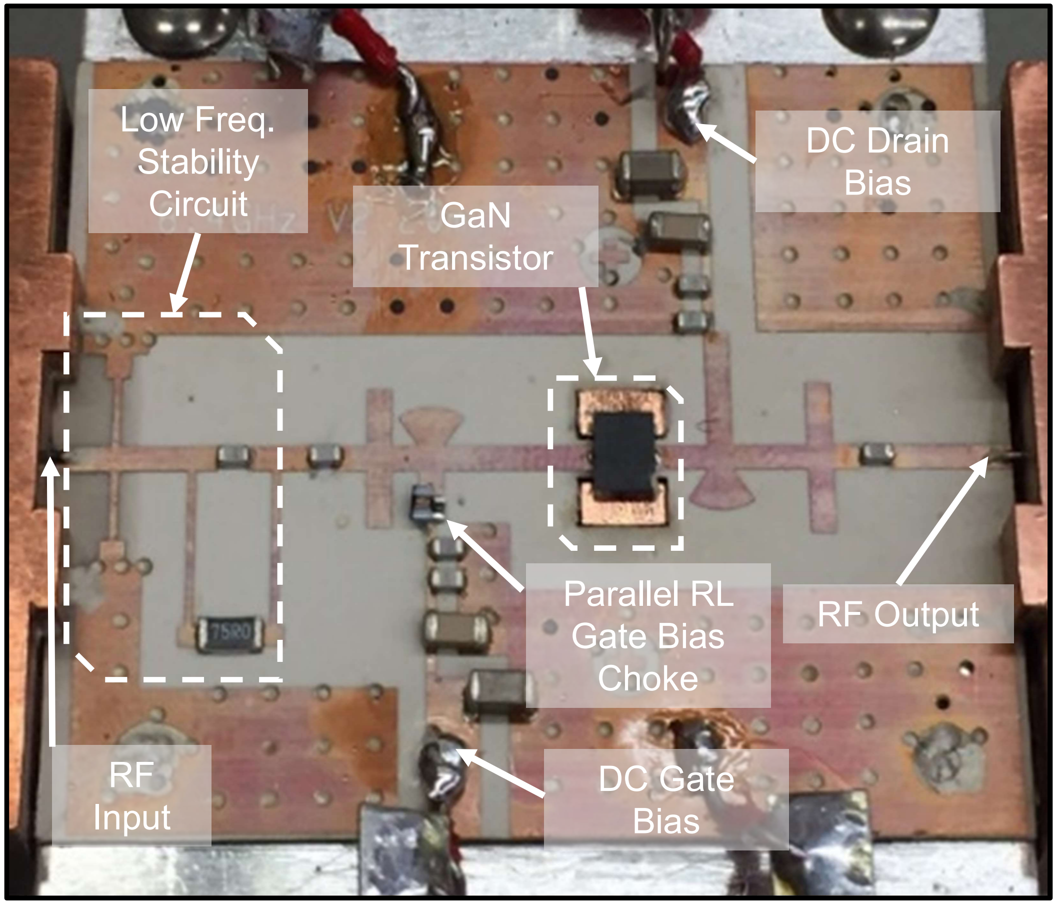


Harmonics are reflected to reshape the voltage and current waveform at the drain



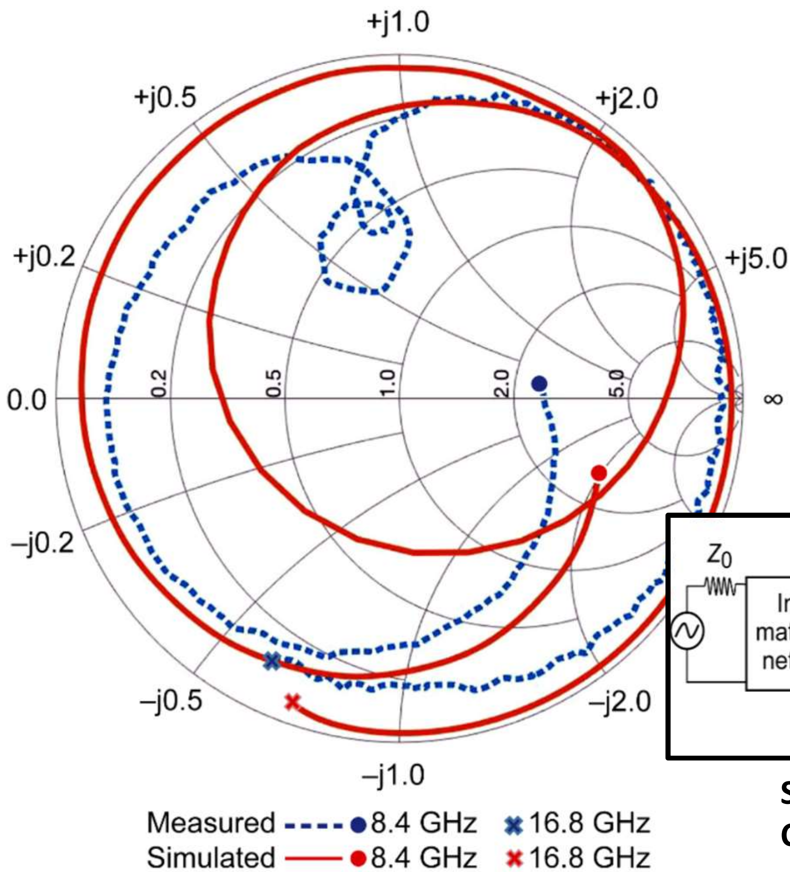
Fabricated Inverse Class-F Amplifier

Transistor: Cree CGHV1F006S 6W, DC-18 GHz, 40V, GaN HEMT

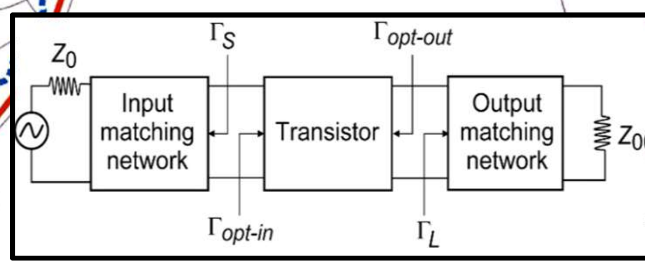


Substrate height, h = 0.02 inch & ε_r = 3.0

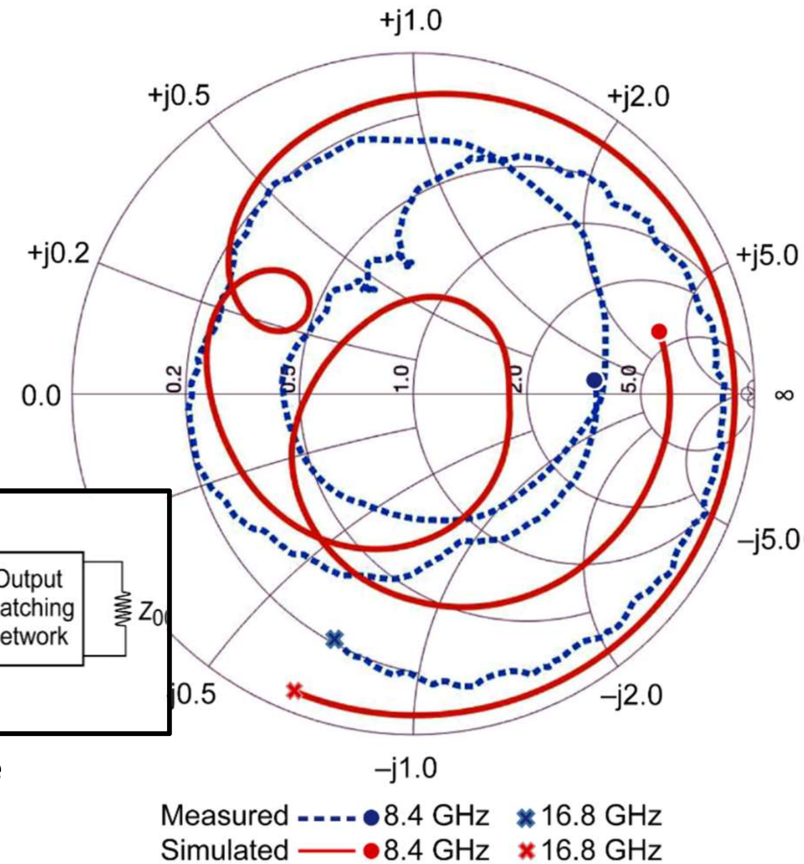
Tuning of Inverse Class-F Amplifier



Simulated and Measured (Γopt-in) parameters of IMN after tuning from 8.4 to 16.8 GHz.

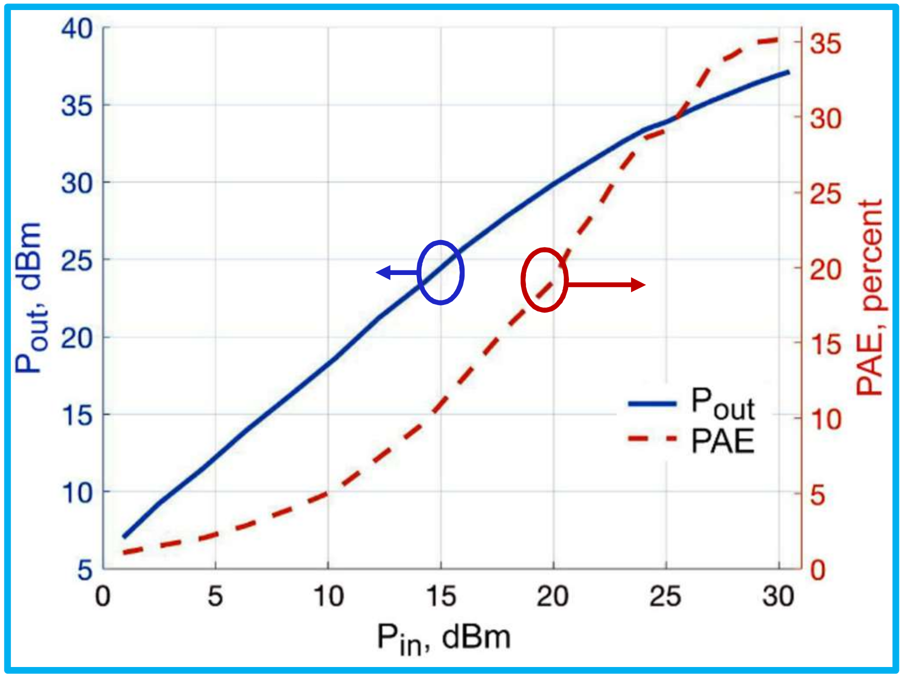


Schematic of the inverse Class-F amplifier design.

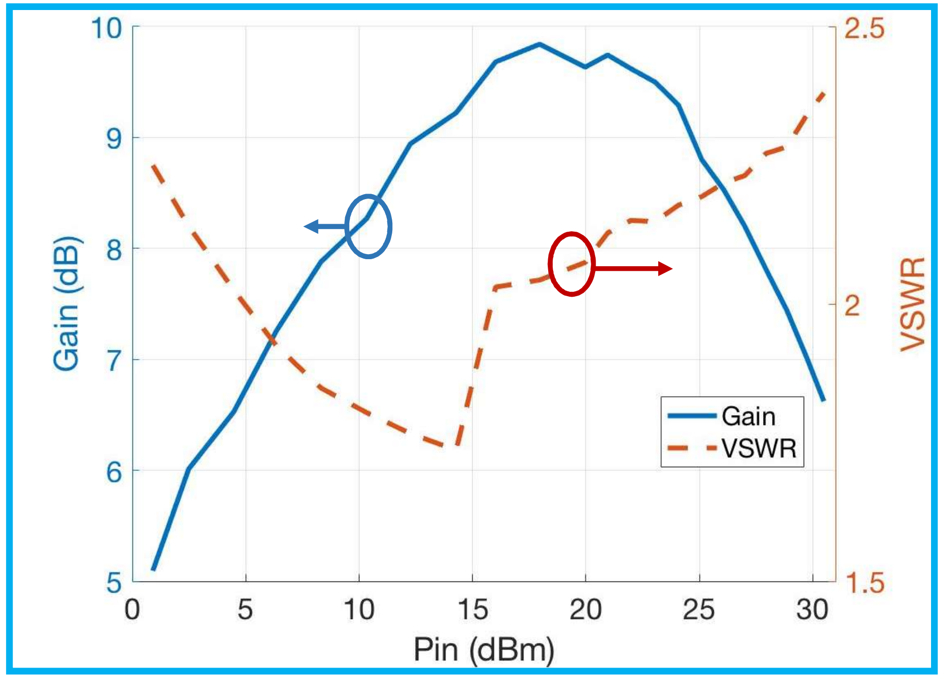


Simulated and Measured (Γopt-out) parameters of OMN after tuning from 8.4 to 16.8 GHz.

Inverse Class-F P_{out}, PAE, Gain and VSWR



Measured P_{out} and PAE vs. P_{in} V_{DS} = 40 V, V_{GS} = -3.2 V and frequency = 8.45 GHz.

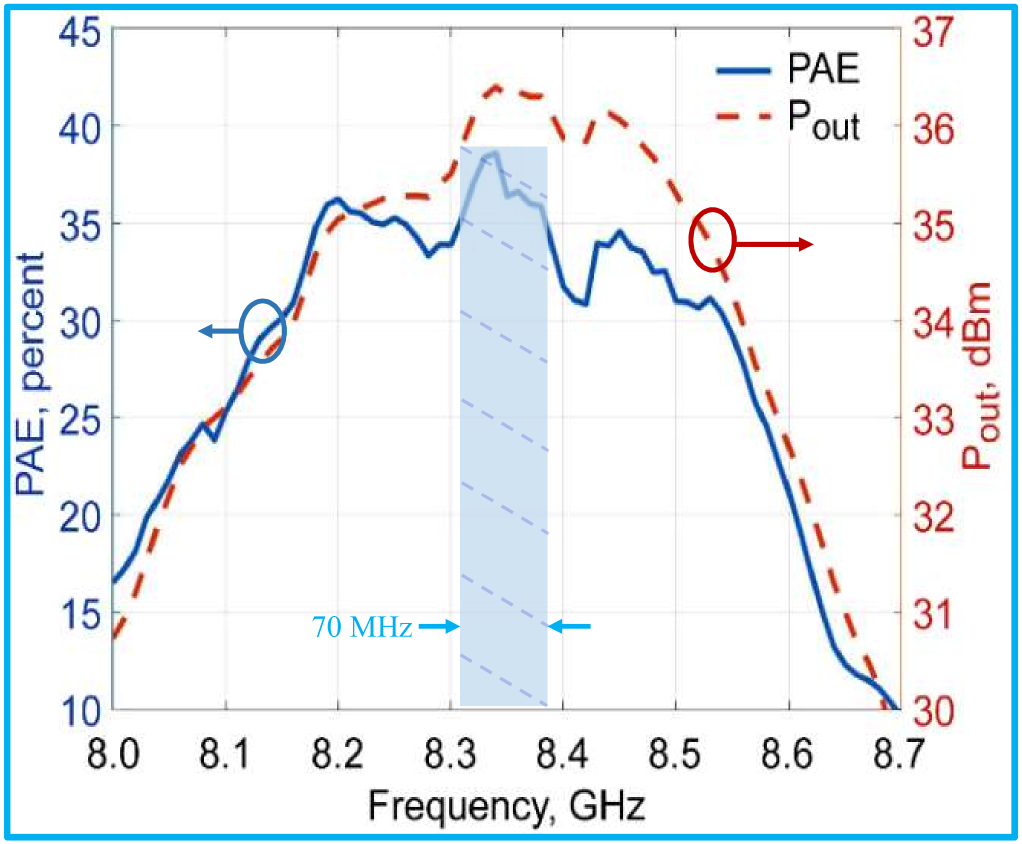


Measured gain and VSWR vs. P_{in} ; V_{DS} = 40 V, V_{GS} = -3.2 V, and frequency = 8.45 GHz

Maximum P_{out} = 5.14-W, PAE = 38.6% with DE = 48.9%

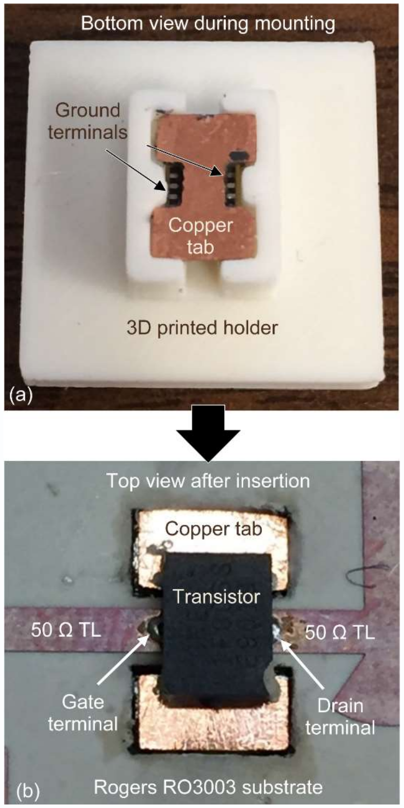
Inverse Class-F Bandwidth

70 MHz bandwidth
where Pout > 36 dBm
and PAE > 35%
8.315 - 8.385 GHz



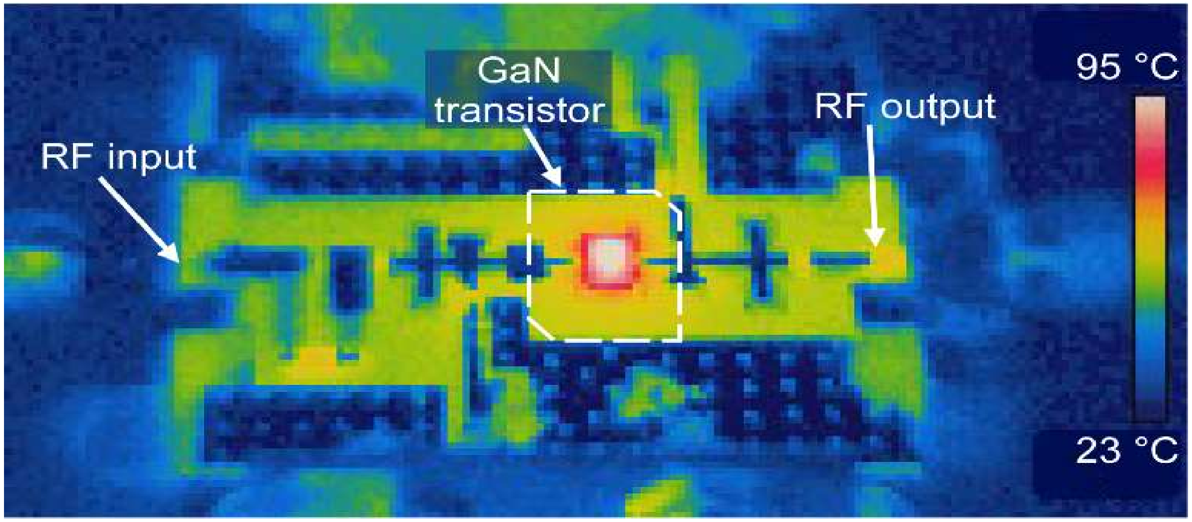
PAE and P_{out} vs. Frequency $V_{DS} = 40$ V, $V_{GS} = -3.2$ V; P_{in} ranges 21.5-30.35 dBm, VSWR ranges 2.4 -33

Thermal Management



CW operation required direct contact between transistor belly and heat sink

Freq. (GHz)	P_{in} (dBm)	V_{DS} (V)	Gain (dB)	PAE (%)	Temp (°C)	P_{out} (W)
8.36	29.9	32	6.3	37.3	95	4.2



Operating conditions observed through thermal imaging

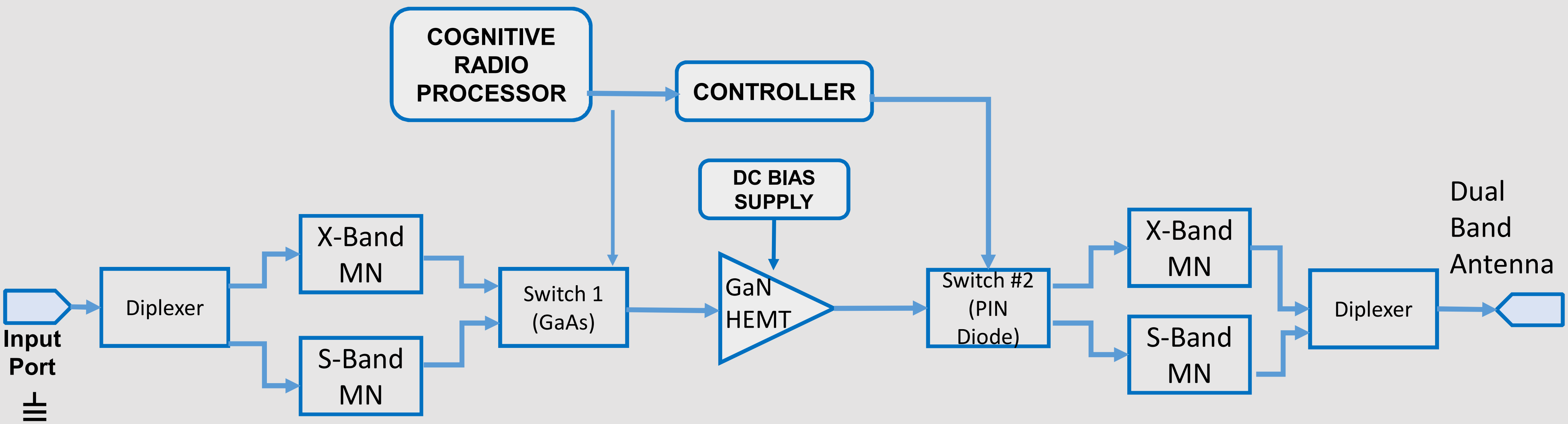
Operating conditions of measured package temp = 95°C :

DC Power Dissipation ≈ 7 W

- Data sheet indicates for package temperature of 95°C, the max allowed power dissipation is ≈ 9 W.

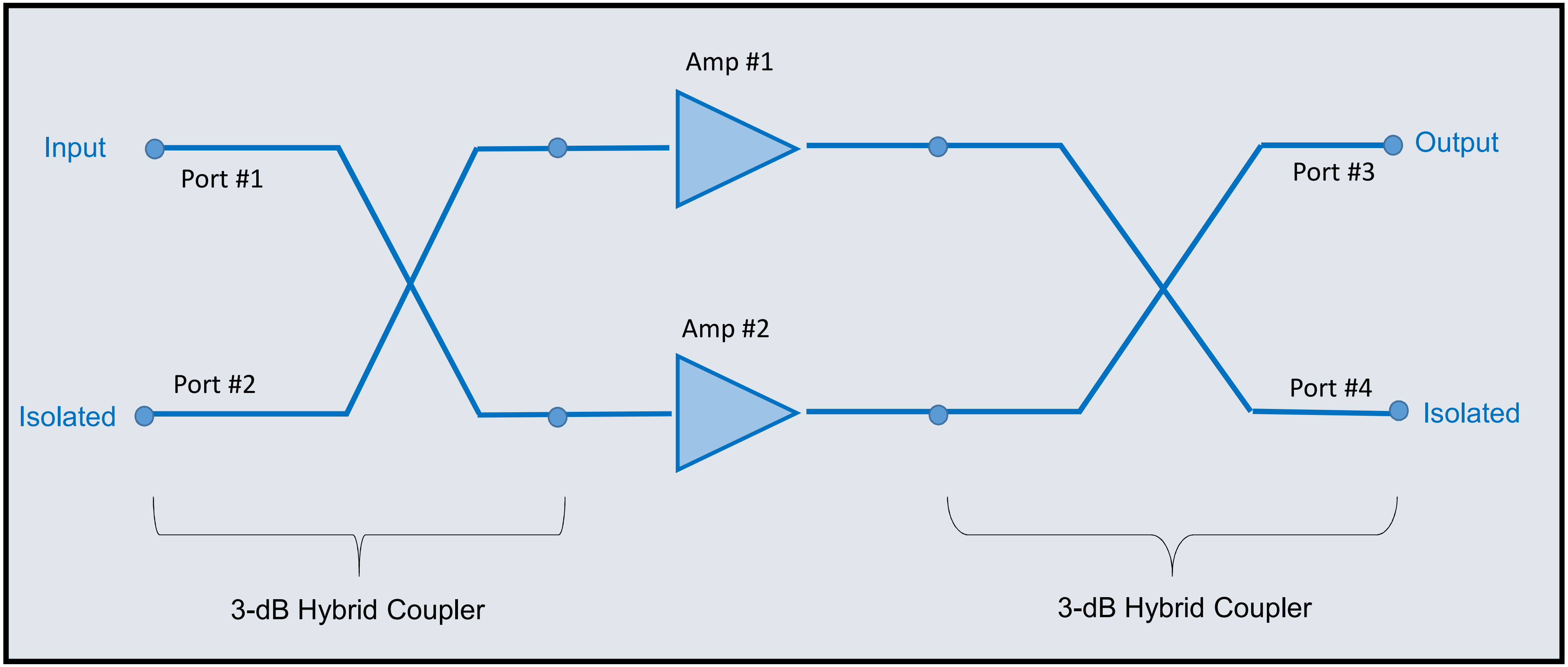
Hence, achieved thermal safety margin of ≈ 22%.

Dual Band Multi-Network Design



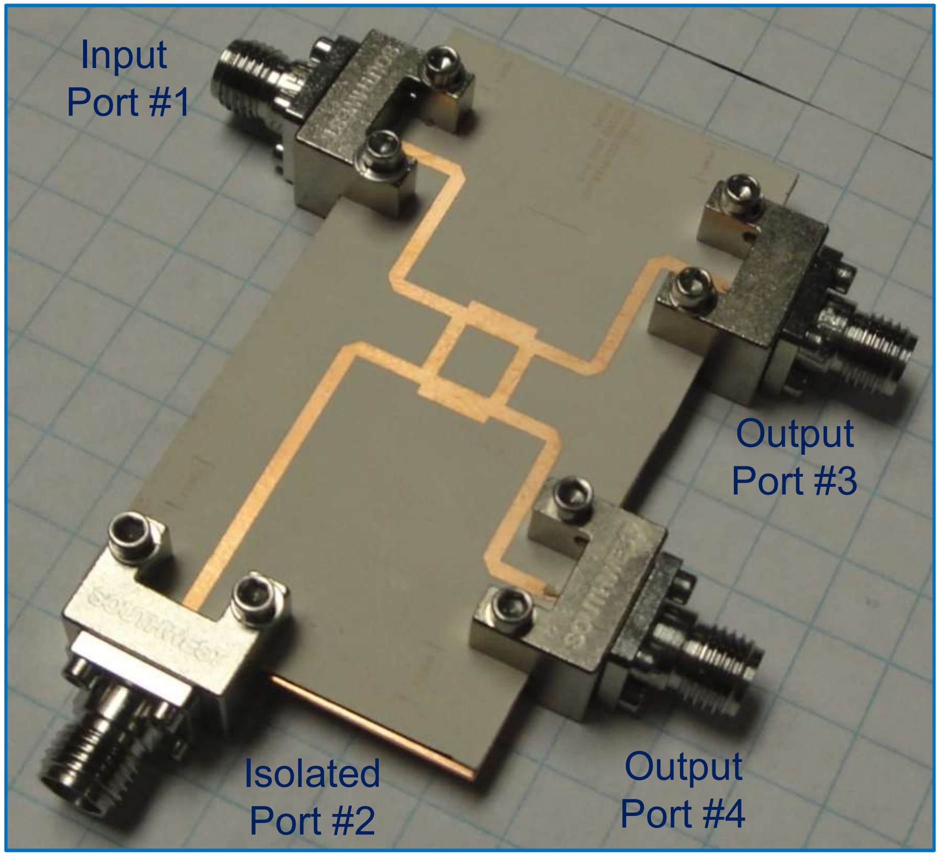
Reconfigurable concept can be applied to dual-band transmitters

Power Variability - Balanced Amplifier



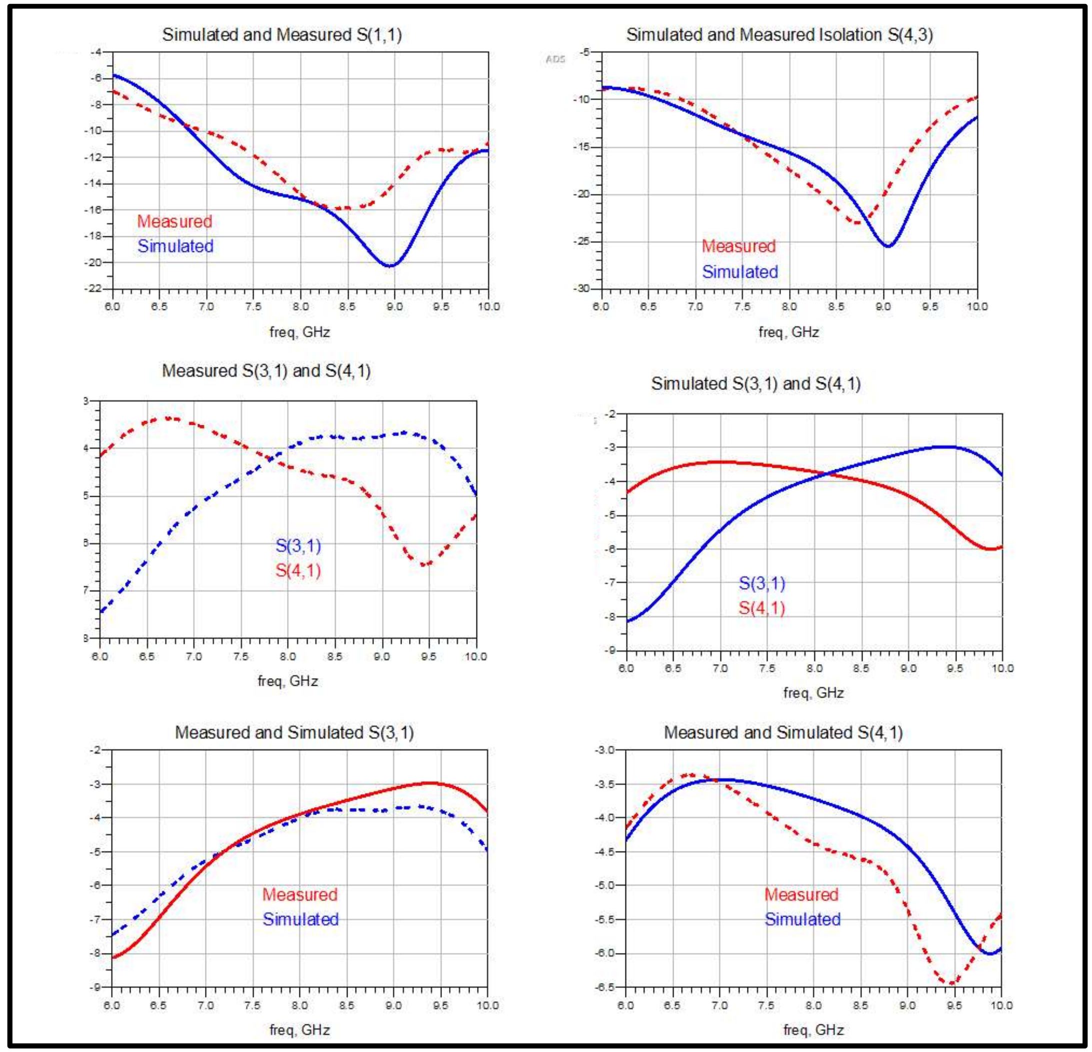
Balanced Amplifier Circuit Topology

Microstrip Branch Line 3-dB Hybrid Coupler

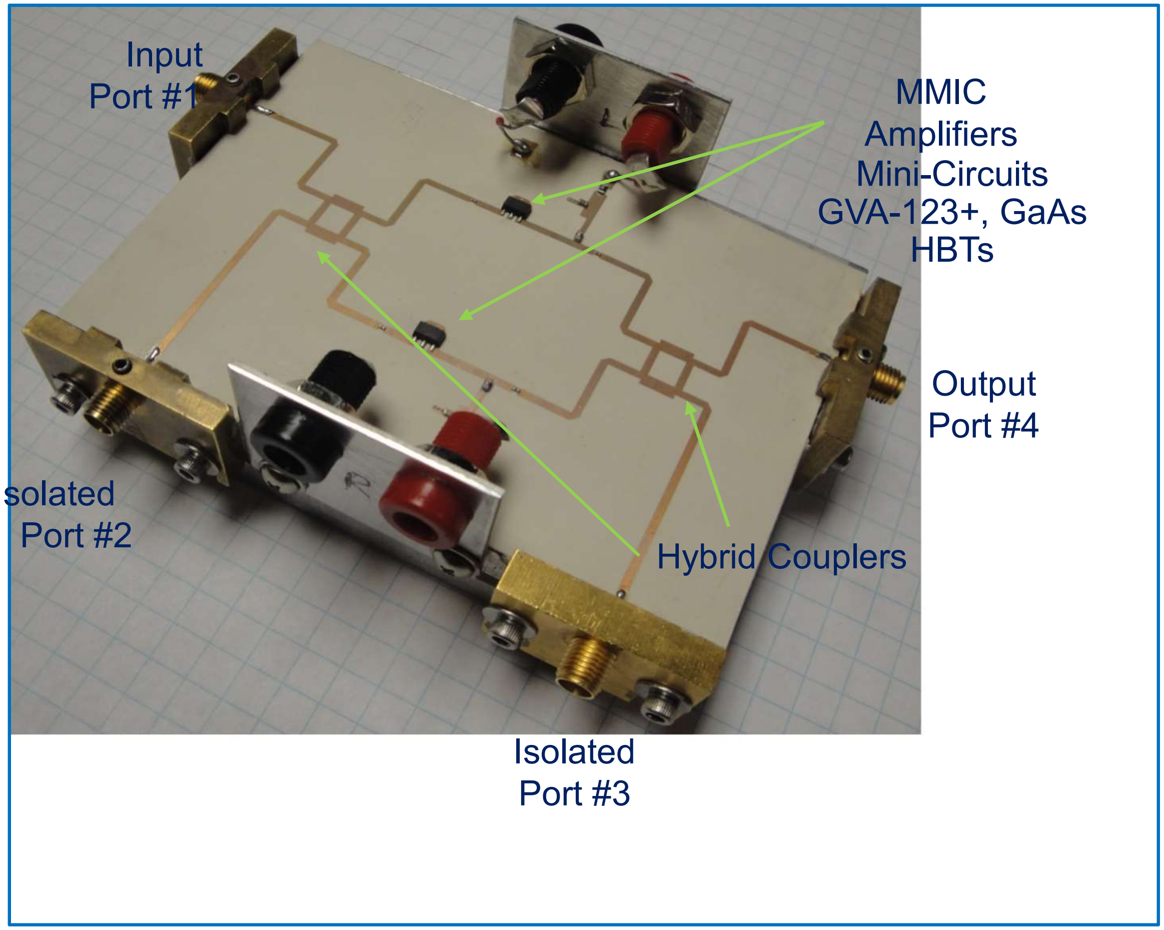


Substrate height, h = 0.02 inch & ε_r = 3.0

Measured vs Simulated Results



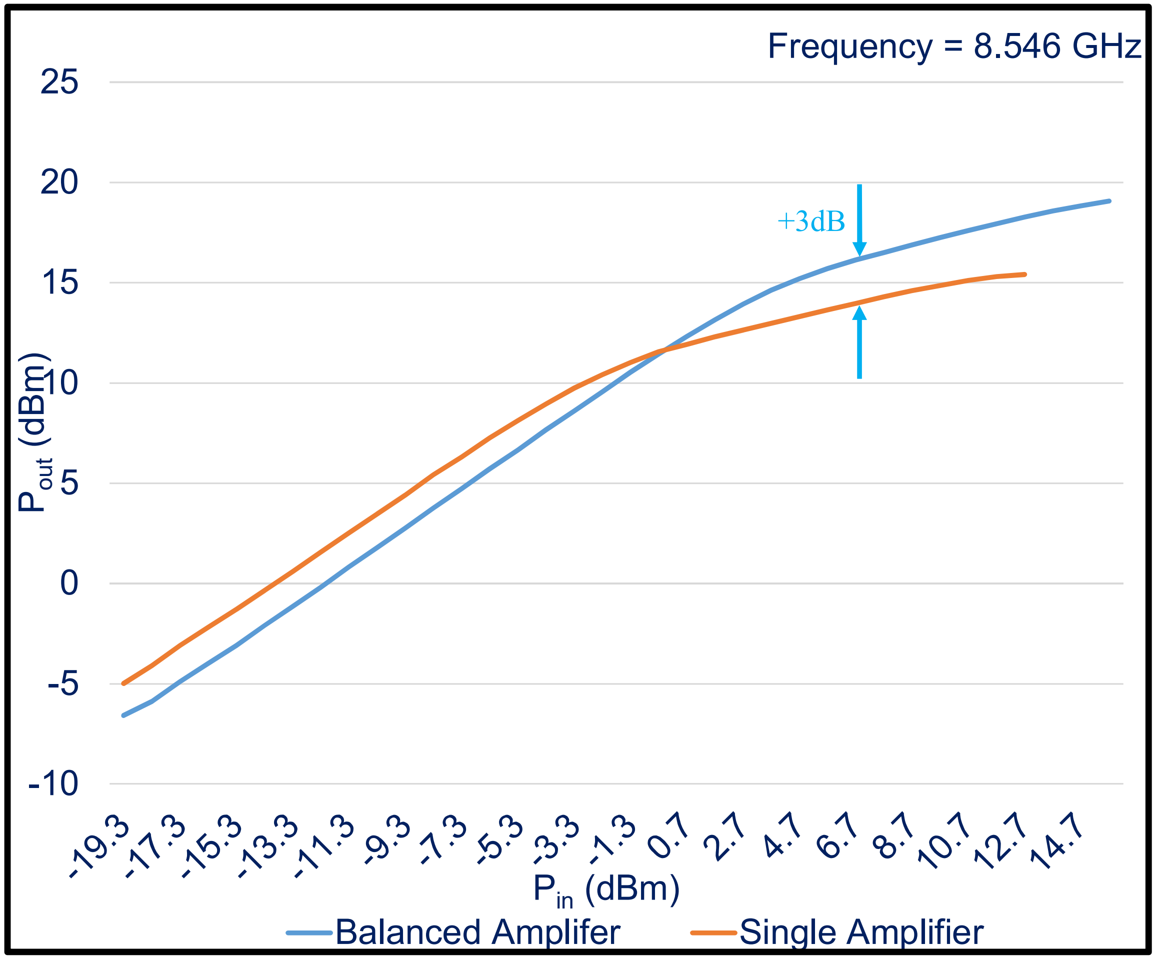
Fabricated Balanced Amplifier



Substrate height, h = 0.02 inch & ε_r = 3.0

P_{in} vs. P_{out} for Single & Balanced MMIC Amplifiers

Balanced amplifier provides a 3dB increase in output power over a single MMIC



Measured P_{out} vs. P_{in} with V_D = 5 V and frequency = 8.546 GHz.

Conclusion

- **Challenges have been presented for achieving the desired high efficiency wide-band operation needed for a cognitive system at X-band**
- **An inverse Class-F GaN SSPA operating at 8.4 GHz has been shown to achieve 5W of output power at 40% PAE with a 70 MHz bandwidth of Pout > 36 dBm and PAE >35%.**
- **A reconfigurable harmonically tuned SSPA has been proposed and justified to provide wideband high efficiency**
- **A balanced amplifier has been presented for additional consideration in reconfigurable power topologies.**